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Calculation of Effectiveness on the Fin Inside One-Tube Plate Finned-Tube Heat Exchanger

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Abstract: The finite difference method in conjunction with the least-squares scheme and the experimental temperature data is proposed to calculate fin effectiveness, on the fin inside one-tube plate finned-tube heat exchangers for various air speeds and the temperature difference between the ambient temperature and the tube temperature. Previous work has been done to predict fin efficiency. Fin effectiveness is also a measure significant in fin study.

I.

Keywords- Heat Exchanger, Fin, Effectiviness.

INTRODUCTION

The fins in heat exchanger are always applied to increase the flow rate per unit area. Tube fin exchangers are extensively used as condensers and evaporators in air conditionings and refrigeration applications, for cooling of water or oil of vehicles or I.C.engines, and as air cooled exchangers in the process and power industries.

Comini et al. 2009 has studied the 'one dimensional design procedure of finned tube heat exchanger' and has assumed that the temperature distribution is one-dimensional.

Nomenclature

$\begin{array}{c} A_{\rm f} \\ A_{j} \\ [A] \\ d_{\rm o} \\ [F] \\ h \\ \bar{h} \\ \bar{h} \\ \bar{h} \\ \bar{h} \\ k \\ L \\ \ell \end{array}$	area of the whole plate fin, m ² area of the <i>j</i> th sub-fin region, m ² global conduction matrix outer diameter of a tube, m force matrix local heat transfer coefficient, W/m ² K unknown average heat transfer coefficient on the whole plate fin, W/m ² K unknown average heat transfer coefficient on the <i>j</i> th sub-fin region, W/m ² K thermal conductivity of the fin, W/m K side length of a square plate fin, m distance between two neighboring nodes in	$\begin{array}{c} Re_{\rm d} \\ r_{\rm o} \\ S_1 \\ T \\ T_j \\ T_{\rm o} \\ T_{\rm o} \\ \Delta T \\ V_{\rm air} \\ X, Y \\ x, y \end{array}$	Reynolds number outer radius of the circular tube, m outer boundary surface of the circular tube temperature temperature measurement on the <i>j</i> th sub-fin region outer surface temperature of the circular tube ambient temperature temperature difference, $T_o - T_\infty$ frontal air speed, m/s spatial coordinates, m dimensionless spatial coordinates
m \bar{m}_j N N_x N_y Q q_j	the x- and y-directions dimensionless parameter defined in Eq. (5) unknown dimensionless parameter on the <i>j</i> th sub-fin region defined in Eq. (10) number of temperature measurements on the fin number of nodes in the x-direction number of nodes in the y-direction total heat flux dissipated from the whole plate fin, W heat flux dissipated from the <i>j</i> th sub-fin region, W	Greek s δ η _f ν θ [θ] Superso cal mea	symbols fin thickness fin efficiency kinematic viscosity of the air, m ² /s temperature difference, $T - T_{\infty}$ global temperature matrix ripts calculated value measured data

Lee kim 2009 has studied 'Air-side heat transfer characteristics of spiral-type circular fin-tube heat exchangers' to investigate the air-side heat transfer characteristics. Lee et al. 2010 has studied 'Air-side heat transfer characteristics of flat plate finned-tube heat exchangers with large fin pitches under frosting conditions.

Chen et al. 2012 studied the 'Study of heat-transfer characteristics on the fin of two-row plate finned-tube heat exchanger' and

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applied the experimental and numerical inverse methods to determine the average heat transfer coefficient and heat transfer coefficient under the isothermal situation on a vertical square fin of the two-row plate finned-tube heat exchangers.

II. ANALYSIS

In this study fin is analyzed to calculate fin effectiveness on one fin inside one-tube plate fin. Fin is inserted in tube of circular shape and air is flowing in cross flow direction and water is flowing through the tube, and thus heat is transmitted. To study, the fin is divided into six sub fin region.



Figure1. Schematic diagram of on tube plate fin.

This shows the physical model of the two-dimensional thin plate fin inside a one-tube plate fin heat exchanger, where ro, L and d denote the outer radius of the circular tube, the side length of the square plane fin and the fin thickness, respectively. The "insulated tip" assumption can be an adequate approximation provided that the actual heat flux dissipated through the tip. Under the assumptions of the steady state and the constant thermal properties, the two dimensional heat conduction equation for the continuous thin fin inside a plate finned-tube heat exchanger.

 $\partial^2 T/\delta X^2 + \partial^2 T/\delta Y^2 = 2h(X, Y)(T-T\infty)/k\delta$ Its corresponding boundary conditions are(1)



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$\partial T/\partial X=0$, at X=0 and X=L	(2)
$\partial T/\partial Y=0$, at Y=0 and Y=L	(3)
T=T0 (X, Y) on S1	(4)
Where T is the fin temperature. X and Y are Cartesian coordinates.	
S1 denotes the boundary of the circular tube with radius ro. k is the thermal cond	luctivity of the fin.
For convenience of the inverse analysis, the following dimensionless parameters	are introduced as-
x=X/L, y=Y/L, and m(x, y)= $2L^{2}h(x, y)/k \delta$	(5)
Substitution of Eq. (5) into Eqn (1)–(4) gives the following equations-	
$\partial^2 \theta / \partial x^2 + \partial^2 \theta / \partial y^2 = m(x, y) \theta$	(6)
$\partial \theta / \partial x = 0$, at x=0 and x=1	(7)
$\partial \theta / \partial y=0$, at y=0 and y=1	(8)
And	
$\theta=0$ (x, y) on S1	(9)
Where $\theta = T - T \infty$	

In the present study, the whole plate fin is divided into N sub-fin regions. The heat transfer coefficient on each sub-fin region is assumed to be constant. With the application of the finite difference method to Eq. (6) can produce the following difference equation on the kth sub-fin region as-

$$(\theta_{i}+1, j - 2\theta_{i}, j + \theta_{i}-1, j)/l^{2} + (\theta_{i}+1, j - 2\theta_{i}, j + \theta_{i}-1, j)/l^{2} = \overline{m}k\theta_{i}, j$$
(10)
For k=1,2,3,...,N

Where, 1 is the distance between two neighbouring nodes in the x- and y-directions and is defined as-

l = 1/(Nx-1) = 1/(Ny-1)

where Nx and Ny are the nodal numbers in x- and y-directions, respectively. \overline{mk} denotes the unknown dimensionless parameter on the *k*th sub fin region and is defined as \overline{mk} = $2L^{2}hk/(K\delta)$, where hk denotes the average heat transfer coefficient on the *k*th sub fin region.

Rearrangement of eqn (10) in conduction with difference equations in the neighbouring of the circular tube can yield the following matrix equation.

(18)

 $[\mathbf{A}][\boldsymbol{\theta}] = [\mathbf{F}]$

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Where [A] is global conduction matrix. $[\theta]$ is a matrix representing the nodal temperature. [F] is a force matrix. With this a set of N algebraic equations are obtained, and by solving equations, heat transfer coefficient, and heat transfer are obtained for sub-fin region.

III. FIN EFFECTIVENESS

Effectiveness is a measure of thermal performance of a heat exchanger. It is defined for a given heat exchanger of any flow arrangement as a ratio of the actual heat transfer rate from the hot fluid to the cold fluid to the maximum possible heat transfer rate qmax thermodynamically permitted. "It is defined as the ratio of the fin heat transfer rate to the heat transfer rate that would exist without the fin".

The effectiveness of the plate fin ε is calculated from the formula-

$$\varepsilon = q with fin/q w/o fin$$
$$\varepsilon = \sqrt{(kp/hA)}$$
$$\varepsilon = \sqrt{(k/h\delta)}$$

 $\varepsilon_{fin} = 1$ Does not affect the heat transfer at all.

$$\mathcal{E}_{fin} < 1$$
 Fin act as insulation (if low k material is used)

Enhancing heat transfer (use of fins justified if ϵ_{fin} >2) $\varepsilon_{fin} > 1$

IV. RESULT

In this work attempt has been made to calculate fin effectiveness for various velocity of air flowing through plate fin. Heat transfer coefficient for different sub fin region is calculated first and then effectiveness.

	V1	V2	V3	V4	V5		
h1	5.5875	5.5869	7.5878	9.6146	10.4938		
h2	5.7941	15.5606	18.9656	18.4412	25.9454		
h3	5.3104	6.6349	8.6208	11.0224	12.8045		
h4	5.1242	9.211	9.2462	12.1108	12.9194		
h5	43.8683	47.5002	96.4123	131.7694	157.7106		
h6	11.3691	12.3908	41.2363	39.8819	38.4363		

The result has been shown below for the three different material steel, aluminum, and copper. The thermal conductivity of these three materials are-

Ksteel = 14.5 W/mk Kal=200 W/mk Kcu=400 W/mk

εsteel	25	22	16	15	14
εal	69	61	45	40	38
εcu	80	71	52	47	44

V. CONCLUSION

It is seen that aluminum is preferred for fin material of a heat exchanger, because it has low cost, low weight, and ability to resistance corrosion. Though the effectiveness of copper is more than the aluminum but cost of aluminium is cheaper than copper. Thus from economic point of view aluminium is used as fin material. Effectiveness of fin made of copper is more than aluminium, because the thermal conductivity of copper is more.

The variation of effectiveness with velocity of air for three material are shown below-



Variation of ε under various ΔT conditions for steel



Variation of ε under various ΔT conditions for aluminium



Variation of ε under various ΔT conditions for copper

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